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Increased Theta Activity in Quantitative Electroencephalographic (QEEG) Measurements During Exposure to Complex Weak Magnetic Fields

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Previous research has shown that exposure to circumcerebral weak magnetic fields with different rates of acceleration applied in a counterclockwise rotation around the head was associated with increased estimations of subjective time and as much as a 30% increase in power within the theta range within quantitative electroencephalographic (QEEG) recordings. The largest effect was associated with magnetic fields applied with 20 ms rates of change through each of the successively stimulated, equally spaced, 8 circumcerebral solenoids. The purpose of the present study was to compare the intracerebral power spectra associated with the rotation of the same patterns in either the clockwise or counterclockwise direction. The results generally replicated previous reports and showed enhanced power over regions of the left hemisphere during clockwise rotations and over the right hemisphere during counterclockwise rotations. These results were considered congruent with the creation of "interference patterns" between the rostral-caudal generation of endogenous cerebral magnetic fields putatively associated with consciousness and the spatial direction of the applied rotating magnetic fields.

Keywords Quantitative electroencephalogram (QEEQ); Weak complex magnetic fields; Hemisphere; Theta activity; Circumcerebral rotations.

Introduction

The electromagnetic bases of consciousness have been attributed to complex magnetic configurations existing as a field that is cohesive over large areas of cerebral space. Llinas and Pare (1991) and Llinas and Ribary (1993) showed that the "binding factor" or "cohesive" associations between frequency and amplitude occurred over cerebral cortical spaces of several tens of millimeters. Changes within these fields showed recursive phase-modulations and derivatives that were within the 10–20 ms range between the rostral and caudal poles of the cerebrum. Continuously repeated increments of between 20–25 ms for the creation and "recreation" of consciousness as a re-entrant process (Edleman, 1989) were considered essential by Tononi and Edelman (1998).

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Direct effects of very weak magnetic fields upon the electromagnetic bases of human consciousness (McFadden, 2002) have been unlikely because it was considered a "complex" process. However, Persinger calculated that the 40–45 Hz increment (20–25 ms intervals) of electroencephalographic activity classically associated with "consciousness" may be embedded as second or higher derivatives (Nunez, 1995) within the theta (4–8 Hz) band (Persinger, 1999). If the fundamental operational intensity of the brain is within the picoTesla range, as suggested by Anninos et al. (1991), then very weak magnetic fields applied with the appropriate spatial geometry and temporal derivatives may directly interface with the cerebral cortices. This should be manifested as both changes in higher order functioning, such as time experience, and power densities within particular electroencephalographic bands. Cook et al. (1999) were the first to report that a specific configuration of weak (1 microTesla) magnetic fields that were rotated around the head in a counterclockwise direction (as seen from the top) was associated with significant changes in subjective time estimation. The duration of the temporal distortion was directly related to the numbers of rotations that were hypothesized to interfere with the recursive rostral-to-causal cohesive cerebral fields generated every 10–20 ms. The subjective temporal distortion did not occur when the same configurations were rotated in the clockwise direction. These authors hypothesized that the counterclockwise rotation of the applied field affected the rostral caudal phase modulations of the brain's electromagnetic field within the right hemisphere by generating "interference patterns".

However, we have not directly compared the intricate changes in electroencephalographic power for clockwise and counterclockwise presentations. Our previous research (Richards et al., 2002; Persinger et al., 2003; Tsang et al., 2004) involved strictly counterclockwise rotations because of the observed effects upon subjective time experience (Cook et al., 1999) and our interests in the phenomenological characteristics of "time travel" within brain space. Richards et al. (2002) found a maximum increase of about 30% in *relative* power within the theta range (4–8 Hz) when the duration of the field presentation at each of the 8 solenoids was 20 ms. Subsequent analyses showed increased power within the 5.0–5.9 Hz range within the right hemisphere compared to the left which is the specific increment predicted by Persinger (1999) to contain intrinsic or hidden derivatives subserving at least some components of consciousness.

The purpose of the present study was to measure the empirical differences between clockwise and counterclockwise rotations with the same pattern of magnetic fields through quantitative electroencephalograms (QEEGs). In order to minimize between-subject variance due to impedances and differential scalp characteristics, we employed, as we did in previous studies, within subject standardized scores for changes in power over each of the four lobes of the two hemispheres during exposures to the different field configurations. The two types of within subject standardized measures are relative changes, compared to no-field baselines, and intrasubject z-scores, where each measure during successive exposures to various field configurations is compared to the mean of the power values for all configurations and divided by their standard deviations.

Methods

Subjects

A total of 12 male and female volunteers between the ages of 20 and 25 years were recruited from a first-year psychology course. Students received bonus marks for participation.

Procedure

After receiving informed consent, the subjects were shown the apparatus. It was a device consisting of eight pairs of solenoids placed equidistantly around the horizontal plane above the ears. The magnetic fields generated from the pairs of solenoids in each canister ranged between 5 and 10 microT at the level of the skull. The details of these measurements have been published elsewhere (Tsang et al., 2004).

Each subject sat in a comfortable arm chair. Sensors were attached with EC-1 paste on the scalp over the left and right frontal lobes (F7, F8), parietal lobes (P3, P4), temporal lobes (T3, T4), and occipital lobes (O1, O2) in accordance with the 10/20 system of electrode placement. All measurements were monopolar referenced to the earlobe. We selected this procedure rather than bipolar comparisons in order to increase the direction and magnitude of any potential differences within a given hemisphere. Monpolar references to the ear are often used in QEEG protocols (Silberstein et al., 2003). Participants were blindfolded and given disposable ear plugs for the purpose of minimizing incidental sound levels.

Electroencephalographic signals were extracted by Labview software that acquired information at a rate of 1,000 samples per second. Fast Fourier Analyses software filtered the raw data and the power in millivolts into delta (1–3.9 Hz), theta (4.0–7.9 Hz), low alpha (8.0–10.4 Hz), high alpha (10.5–13.0 Hz), low beta (13.1–20 Hz), and gamma (35–45 Hz). Because one of the major electroencephalographic correlates of human consciousness was hypothesized (Persinger, 1999) to exist as a second or third derivative within the theta range, the power within serial 1 Hz increments (3.0–3.9 Hz, 4.0–4.9 Hz, 5.0–5.9 Hz, 6.0–6.9 Hz, 7.0–7.9 Hz, 8.0–8.9 Hz) was also collected within and around (''peritheta'') this interval.

The procedure involved sampling 20 s of electroencephalographic data during baseline (before the magnetic fields were activated) and then 2.5 min after the initiation of each of 6 different patterns. The duration of each magnetic field pattern was 5 min separated by 30 s of no field. The patterns were the same as those employed in previous studies and are shown for convenience in Table 1. The burst-firing pulse and frequency-modulated (Thomas) pulse (Thomas et al., 1997) was generated from the computer software to the commutator. Their shapes have been also published previously (Persinger, 2003). The point or pixel duration was the time in ms the voltage value that generated each successive point (a value between 0 and

Table 1

Parameters for patterns (P) of magnetic field configurations presented in both the clockwise and counterclockwise directions. All times (t) are in ms. BF = burst firing; FF = frequency-modulated. Pulse = (P1, P2, P3) vs. (P4, P5, P6) while Phase = (P1, P4) vs. (P2, P5) vs. (P3, P6)

Variable	P1	P2	P3	P4	P5	P6
Pulse shape	BF	BF	BF	FF	FF	FF
Pixel t	1	1	3	1	1	3
Interstimulus t	1	1	3000	1	1	3000
Solenoid t	20	100	200	20	100	200
Rate of change	$t+2$	$+20$	-2	$+2$	$+20$	-2

256 which corresponded to an increment of voltage between −5 and +5 V) that composed the pulse occurred (Persinger, 2003). The interstimulus duration was the time between each pulse in milliseconds.

The rotational features of the field around the skull were influenced by the commutator rate and the change-in-rate. The commutator values indicated the solenoid time; this was the duration the field was localized to the first pair of solenoids in the cycle (the left prefrontal for counterclockwise rotation and the right prefrontal for clockwise rotation) while the change in rate referred to the change in duration of the field at each successive pairs of solenoids. A positive value reflected acceleration while a negative value reflected slowing. For example, 20, +2 indicated that the time at each of the successive 8 pairs of solenoids (solenoid time) was 20, 18, 16, 14, 12, 10, 8, and 6 ms, respectively. The parameters 200, −2 means the presentation of the field at each successive pair of solenoids was 200, 202, 204, 206, 208, 210, 212, and 214 ms. The 100 ms, +20 ms pattern indicated that the solenoid time was 100, 80, 60, 40, and 20 ms over the first 5 solenoids while the time in each of the 3 remaining solenoids was 1 ms each.

All parameters were selected on the bases of both theoretical extrapolations and empirical observations. As a result the cerebral magnetic fields of the subjects were exposed to applied, artificial complex magnetic fields that changed as increments or rates of change around the 20 ms range, the median value associated with the continuous "recreation" of consciousness (Edleman, 1989). These fields were also rotated in space at various velocities, associated with each of the six patterns, around the heads of the subjects.

The rotational frequencies ranged from 9.6 times per s (Patterns 1 and 4) to 3.3 times per s (Patterns 2 and 4) to 0.6 times per s (Patterns 3 and 6). Corresponding rotational velocities around the head, assuming a circumference of 0.6 m, were 5.8 m/s, 2 m/s, and 0.4 m/s. For the 20 ms solenoid duration with 2 ms derivatives, the acceleration exceeded 9.8 m/s^2 between the 7th and 8th pairs of solenoid that were over the posterior portion or rostral pole, respectively, of the left or right frontal lobe, depending upon the rotational direction. Six of the subjects received the clockwise rotations (starting with the right prefrontal and rotating to left prefrontal) while the other six subjects received the counterclockwise rotations (starting with the left prefrontal and rotating to the right prefrontal). Half the numbers of subjects in each rotational direction received the patterns (Table 1) in the opposite order.

The basic design was a four-way analysis of variance with four within subject levels (lobe, hemisphere, pulse, and phase). Analyses were completed separately for each of the six wide-band frequencies and for each of the six, 1-Hz bands within the peritheta range. Measures for the group exposed to the counterclockwise and clockwise fields were analyzed separately to enhance discernment of any effect and to facilitate clarity.

In order to minimize individual differences, relative scores and z-scores were utilized instead of raw scores. Relative scores were calculated by dividing the raw scores for each sensor (hence each lobe and each hemisphere) for each frequency band during the six different presentations of magnetic field patterns by the baseline activity when no field was presented. Z-scores were calculated by subtracting the raw score for each of the six sensor (EEG electrode) positions (two hemispheres, four lobes) from the mean for the values for all six positions and dividing this quantity by the standard deviation for the values for all six positions. This was completed for each of the six wide and 1-Hz frequency bands. All analyses involved SPSS software on a VAX 4000 computer.

Results

The maximum relative increases (primarily) or decreases in power within specific bands for the various subgroups of the analyses were within the range of +/− 20–30%. For parsimonious presentation (see Richards et al., 2002; Persinger et al., 2003), the eta-squared values (the amount of variance explained) instead of F values or probability levels for each of the combinations of the within subject levels (lobe, hemisphere, pulse, and phase) are presented in Tables 2, 3, and 4 for the subjects who received the clockwise (C) and counterclockwise (CC) rotations separately. Only those effects that were statistically significant at the $p < 0.05$ level, indicated by asterisks, are discussed. Most of the main effects or first order interactions were secondary to higher order interactions and hence are also not discussed.

The statistically significant interactions between lobes and hemispheres for relative power within the theta (4–7.9 Hz), low alpha (8–10.5 Hz), high alpha (10.6–13 Hz), and low beta (13.1–20 Hz) bands during clockwise rotation were *not* evident for same field patterns presented in the counterclockwise direction. Post hoc analyses indicated that the interactions between lobes and hemispheres for power within the theta and low alpha bands during the clockwise rotations were due primarily to the increased power over the left frontal region compared to the right parietal region.

On the other hand, this interaction for the high alpha band was due primarily to the increased power over the left frontal region compared to the right and left occipital lobes. Within the low beta range the increased power within the left prefrontal

Table 2
Percentage of explained variance (partial eta-squared values) for main effects and interactions for relative changes in power of electroencephalographic activity within the delta, theta and low-alpha ranges over the two hemispheres and four lobes during applications of the two pulses and three phases presented in either clockwise (C) or counterclockwise (CC) directions

	C	CC	C	CC	C	CC
Lobe (L)	2	3	3	5	10	8
Hemisphere (H)	3	22	0	3	34	4
Pulse (Pu)	23	26	12	28	26	10
Phase (Ph)	28	43*	5	4	26	11
L × H	23	5	46*	18	42*	21
L × Pu	3	5	14	16	16	6
L × Ph	34	5	11	12	21	11
H × Pu	1	9	21	0	7	10
H × Ph	31	7	2	2	14	16
Pu × Ph	7	11	0	3	40	13
L × H × Pu	3	35	29	27	28	1
L × H × Ph	9	16	4	33*	13	25
L × P × Ph	5	19	5	11	13	12
H × P × Ph	20	3	7	28	46*	22
L × H × Pu × Ph	11	34*	21	9	32	20

$p < 0.05$ for within subject measures.

Table 3
Percentage of explained variance (partial eta-squared values) for main effects and interactions for relative changes in power of electroencephalographic activity within the high alpha, beta, and gamma ranges over the two hemispheres and four lobes during applications of the two pulses and three phase presented in either clockwise (C) or counterclockwise (CC) directions

	High alpha		Low beta		Gamma	
	C	CC	C	CC	C	CC
Lobe (L)	5	35	2	3	13	5
Hemisphere (H)	4	1	12	42	9	15
Pulse (Pu)	31	3	29	48	28	18
Phase (Ph)	14	31	10	13	12	9
L × H	56**	18	42	39	28	50**
L × Pu	16	5	18	10	20	22
L × Ph	30	28	13	31	9	17
H × Pu	7	10	16	2	25	10
H × Ph	11	36	12	32	28	18
Pu × Ph	46*	5	44	32	9	5
L × H × Pu	22	16	20	35	27	33
L × H × Ph	20	15	14	18	6	18
L × P × Ph	16	13	18	17	19	14
H × P × Ph	68**	3	36	10	20	24
L × H × Pu × Ph	56**	20	17	10	7	12

*$p < 0.05$; **$p < 0.01$.

measures was significantly different only from the left occipital measures. The results of the analyses of the 1-Hz increments for the peritheta band for the clockwise rotation (Table 4) for this interaction between lobes and hemispheres showed that the enhancement of the left frontal region compared to the right parietal region was only statistically significant within the 4.0–4.9 Hz, 6.0–6.9 Hz, and 8.0–8.9 Hz increments.

The statistically significant interaction between pulses (frequency-modulated vs. burst-firing), lobes, and hemispheres during clockwise rotation was due to the greater power within the 5.0–5.9 Hz band over the temporal lobe of the left hemisphere during the applications of the burst-firing field compared to the all other combinations. An interaction within the 8.0–8.9 Hz increment was statistically significant. However, in this instance the parietal and occipital lobes displayed greater power over the left hemisphere during the presentation of the burst-firing field compared to all other combinations. The statistically significant four-way interaction between lobes, hemispheres, phases, and pulses within the high alpha band during the clockwise rotation was due in large part to the increased relative power within the left prefrontal compared to the left and right occipital region during Pattern 1 (burst firing with solenoid times of 20 ms and rates of change of 2 ms) compared to other combinations.

From a theoretical perspective, a most important statistically significant interaction occurred between lobes, hemispheres, and phases during the *counterclockwise*

Table 4
Percentage of explained variance (partial eta-squared values) for main effects and interactions for relative changes in power of electroencephalographic activity within successive 1 Hz increments within the peritheta range over the two hemispheres and four lobes during applications of two pulses and three phases presented in a clockwise direction

	Frequency (Hz) increments					
	3–3.9	4–4.9	5–5.9	6–6.9	7–7.9	8–8.9
Lobe (L)	4	6	5	1	10	23
Hemisphere (H)	9	43	1	1	32	47
Pulse (Pu)	34	13	0	20	38	39
Phase (Ph)	4	4	14	8	1	3
L × H	19	45*	39	49*	37	40
L × Pu	8	12	6	37	4	19
L × Ph	30	7	12	13	19	8
H × Pu	5	23	0	51*	23	28
H × Ph	4	0	2	6	9	3
Pu × Ph	5	1	1	3	6	20
L × H × Pu	19	15	44*	29	11	41*
L × H × Ph	5	4	9	8	4	5
L × P × Ph	12	9	15	10	7	6
H × P × Ph	44	19	24	6	16	35
L × H × Pu × Ph	13	22	19	26	16	13

*$p < 0.05$.

rotation only within the peritheta range (Table 4). Post hoc analyses of the 1 Hz increments indicated that the main source of this interaction was due to the enhanced power within the 5.0–5.9 Hz band over the right temporal lobe compared to other regions when the duration of the field at each solenoid was 20 ms and the rate of change (decreased duration at each solenoid) was 2 ms.

Results from the z-scores which reflected the relative changes during the successive presentations of the patterns compared to themselves were similar to the relative changes that reflected alterations in power relative to the no-field baseline. There were two major and potentially important (eta-squared = .60, .55, respectively) additions. The first effect was the marked enhancement ($z_{mean} = 0.7$, $z_{SEM} = 0.05$) of overall power for all measures (two hemispheres and four lobes) for all frequency bands during the counterclockwise rotation only for the burst-firing 20 ms solenoid durations with an accelerating rate of change of +2 ms. For comparison, all of the other counterclockwise rotations for the other 5 patterns and all 6 of the patterns presented in clockwise rotation showed z-scores between −.3 and +.2 with S.E.M.s of between 0.05 and 0.1.

The second effect was the significantly increased (z-scores = 0.5–0.6) power within the 4.0–4.9 Hz, 6.0–6.9 Hz, and 7.0–7.9 Hz during the counterclockwise rotations compared to the clockwise rotations (z-scores = −0.2 to −.2) over the entire brain. Compared to the left hemisphere, the right hemisphere displayed an

approximately 25% increase in power within the 5.0–5.9 Hz range for all six patterns. The effect was particularly pronounced for solenoid times of 20 ms with rates of change of 2 ms.

Discussion

The same complex magnetic field patterns resulted in different changes in power within specific electroencephalographic bands depending upon the direction of circumcerebal rotation in the horizontal plane of the pulses around the head. Consequently, the probability is very low that the changes reported previously (Richards et al., 2002; Persinger et al., 2003; Tsang et al., 2004) for only counterclockwise rotations were due to current artifacts. If the effects were related to induction within the electrodes (sensors), then mirror relationships in effect sizes would have existed within the relevant frequency bands for the clockwise and counterclockwise rotations. This was not observed.

In addition, the significant interactions between specific hemispheres, phases (the time each solenoid was activated and the rate of change regardless of pulse form), and lobes suggest a marked specificity for these circumcerebral fields. The largest and most consistent enhancement of power was noted for the 20 ms phase whose rate of change was 2 ms such that the duration of the field presentation within the first to the eighth pairs of solenoids ranged from 20 ms to 6 ms. The functional frequency range for this change would have been above 50 Hz. This effect was conspicuous during counterclockwise rotations compared to clockwise rotations. Hence, it was not the numbers of rotations but the direction of the rotation that enhanced the electroencephalographic power. The specific enhancement in power by Pattern 1 (where the burst-firing pattern was presented for 20 ms at each solenoid and accelerated by $+2$ ms) but not by Pattern 4 which involved the same rotational parameters but a frequency modulated pulse, further emphasizes the importance of the temporal structure of the applied field.

From our perspective there were three new and important observations from this study. First, clockwise rotation produced enhancements of power primarily over left hemispheric regions while counterclockwise rotation produced enhancements of power primarily over the right hemisphere, particularly the temporal lobes. This observation would be congruent with our concept that weak, physiologically patterned magnetic fields rotating in the horizontal plane around the head generate interference patterns within the electromagnetic manifold of "cerebral space" (Nunez, 1995).

The endogenous transcerebral magnetic fields within this manifold as well as their phase modulations, a probable physical manifestation of the "cohesion factor" by which conscious is produced or with which it is strongly correlated, are generated in a rostral to caudal direction (Llinas and Ribary, 1993). Consequently, when the fields were rotating clockwise the direction of the field would be in opposition (caudal to rostral) when it entered the domain of the left hemisphere. We suggest this interference was associated with increases in relative power over the left hemisphere. On the other hand, during counterclockwise rotation the applied magnetic fields would have generated interference patterns within the right hemisphere. This was also observed, particularly over the right temporal lobes.

The second observation was the asymmetric discrepancies in power between the left prefrontal region (higher) and the right parietal region (lower). If these changes in

electroencephalographic power reflect metabolic activity or function, then this pattern would be consistent with the increase "self awareness" (a classic left prefrontal function) of detachment of the self from the body reported by our subjects. The sensed presence (the feeling of another entity other than the self) which is also reported during circumcerebral stimulation with the patterns employed in this study has been associated with altered perfusion within the frontoparietal regions (Landtblom, 2006).

The third observation was that a counterclockwise spatially rotating field that also involved a rate of 2 ms change for the duration of application starting from an initial value of 20 ms over each of 8 solenoid may directly interact with consciousness. The enhanced (about 20%) increased power within the 5.0–5.9 Hz over the right hemisphere compared to the left replicated the results of Richards et al. (2002). This particular component of theta activity has been hypothesized to be involved with the second and third derivatives of phase modulations that might contribute to extended spatial and temporal properties of consciousness (Puthoff and Targ, 1976).

If the neuroelectromagnetic bases of consciousness is phase-modulated or recursively recreated every approximately 10–20 ms, then these complex phenomena of human experience may exist as successive space-time quanta. One obvious question is what happens to consciousness during that presumably brief but nonetheless quantifiable duration between the end of one "cerebral quantum" and the initiation of the next increment? During this discrete physical time does the cerebral manifold become sensitive or receptive to exogenous (particularly electromagnetic) stimuli to which it is usually "shielded"?

Our working metaphor is that the applied rotating, temporally shifting magnetic fields directly interact or "entangle" with the magnetic fields generated by the brain itself. A macroscopic comparison would be the consequences of the interaction between the magnetic fields expanding from the solar corona within the solar wind and the geomagnetic field. Entanglement and connection of the two sources of flux lines are considered essential processes by which information and energy are mediated within the magnetosphere and the earth's surface (Gosling, 1993).

The weak strength of the applied time-varying magnetic fields should not be confused with the necessity for very strong intensities for static fields for medical imaging as an impediment to their effects. For example, verbal information is exchanged between human brains as pressure waves (speech) or complex time-varying fields with dominant frequencies between approximately 100 and 5,000 Hz and amplitudes within the milliPascal range. Yet, we do not "hear" the "static" atmosphere of about 100 kPa whose pressure waves are more than 10^7 times (between 1–10 kPa) stronger but whose frequencies are within mHz to microHz range. Similarly, the apparent absence of effects from strong Tesla or even milliTesla static magnetic fields would not necessarily indicate that physiologically patterned or resonant magnetic fields of much weaker strengths would not be more biorelevant and bioeffective.

Our brains are immersed in a static geomagnetic field whose strength is about 5×10^{-5} Tesla. Its time-variations, in the order of 1–10 microTesla, are also within the mHz to microHz range. If we assumed that fundamental ratios exist in forces and energies, as does Kolombet (1995) and the ratio for pressure is applicable to magnetic fields, then this would suggest that the operational intensity for information exchange involving magnetic fields within and between brains would be about (10^{-5} T) times 10^{-7} or in the order of 10^{-12} T.

From this perspective the operational range of magnetic intensity of about 1 pT (picoTesla) for the human brain suggested by Anninos et al. (1991) becomes relevant.

The product of the spin (magnetic moment) of an electron (9.28747×10^{-24} J/T) and magnetic field of 1×10^{-12} T (which is 9.28747×10^{-36} J) divided by the square of the velocity of light is 1×10^{-52} kg. This value has recently been shown to be the upper limit of the rest mass of the photon (Tu et al., 2005). Bokkon (2005) suggested that action potential-related biophotons may be the actual process that mediates at least some aspects of consciousness. If Bokkon's hypothesis is supported, then Pribram's (1971) neural holographic models, which are strongly dependent upon interference patterns between photon-like processes, of consciousness become immediately relevant.

Spin has been considered the most important of the four quantum numbers, which describe the unique quantum state of an electron, for determining location of particles. Thus, even at the simplest level there is a rational connection between the state of particle-wave as well as the domains of quantum phenomena and human thought as predicted by Neils Bohr (1958). This simple calculation reiterates the importance of the experimenter maintaining cognitive flexibility when examining the potential effects of these weak complex magnetic fields.

To date, weak, biofrequency magnetic fields have been considered primarily as adverse sources upon physiology and cognition (Cook et al., 2006). We suggest that mechanisms other than variants of current induction involving nonlinear laws (Carrubba and Marino, 2008) when temporal rates of change in the presentation of magnetic fields occur within a circular, rotational "synchrotron" geometry within which human brain is placed. If these assumptions are valid, then very weak magnetic fields applied with the appropriate space-time-variations may be required to interact optimally and naturally with electromagnetic fields associated with consciousness and thinking.

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References

Anninos, P. A., Tsagas, N., et al. (1991). Magnetic stimulation in the treatment of partial seizures. *Int. J. Neurosci.* 60:141–171.

Bokkon, I. (2005). Dreams and neuroholography: an interdisciplinary interpretation of development of homeotherm state in evolution. *Sleep Hypnosis* 7:61–76.

Bohr, N. (1958). *Atomic Physics and Human Knowledge*. New York, John Wiley and Sons.

Carrubba, S., Marino, A. A. (2008). The effects of low-frequency environmental-strength electromagnetic fields on brain electrical activity: a critical review of the literature. *Electromagn. Bio. Med.* 27:83–101.

Cook, C. M., Koren, S. A., Persinger, M. A. (1999). Subjective time estimation by humans is increased by counterclockwise but not clockwise rotation of phase-shifting magnetic pulses in the horizontal plane. *Neurosci. Lett.* 268:61–64.

Cook C. M., Saucier, D. M., et al. (2006). Exposure to ELF magnetic fields and ELF-modulated radiofrequency fields: the time course of physiological and cognitive effects observed in recent studies (2001–2005). *Bioelectromagnetics*. DOI: 10.1002/bem.20247.

Edleman, G. M. (1989). *The Remembered Present*. New York, Basic Books.

Gosling, J. T. (1993). Coronal mass ejections: the link between solar and geomagnetic activity. *Phys. Fluids B* 5:2638–2645.

Kolombet, V. A. (1995). Biological physics. *Biophysics* 40:1137–1146.

Landtblom, A. M. (2006). The ''sensed presence'': an epileptic aura with religious overtones. *Epilepsy Behav*. 9:186–188.

Llinas, R., Pare, D. (1991). On dreams and wakefulness. *Neuroscience* 44:521–555.

Llinas, R., Ribary, U. (1993). Coherent 40-Hz oscillations characterize dream state in humans. *Proc. Nat. Acad. Sci*. 90:2072–2081.

McFadden, J. (2002). Synchronous firing and its influence on the brain's electromagnetic field: evidence for an electromagnetic theory of consciousness. *J. Consciousness Stud*. 9:23–50.

Nunez, P. L. (1995). Towards a physics of the neocortex. In: Nunez, P. L., ed. *Neocortical Dynamics and Human EEG Rhythms*. New York, Oxford University Press, pp. 68–132.

Persinger, M. A. (1999). Is there more than one source for the temporal binding factor for human consciousness? *Percept. Motor Skills* 89:1259–1262.

Persinger, M. A. (2003). Neurobehavioral effects of brief exposures to weak intensity, complex magnetic fields within experimental and clinical settings. In: McLean, M. U., Engstrom, S., Holocomb, R. R., eds. *Magnetotherapy: Therapeutic Benefits and Adverse Effects*. New York, TFG Press, pp. 89–117.

Persinger, M. A., Koren, S. A., Tsang, E. W. (2003). Enhanced power within a specific band of theta activity in one person while another receives circumcerebral pulsed magnetic fields: a mechanism for cognitive influence at a distance? *Percept. Motor Skills* 97:877–894.

Pribram, K. H. (1971). *Language of the Brain: Experimental Paradoxes and Principles of Neuropsychology*. Englewood Cliffs, NJ, Prentice Hall.

Puthoff, H. E., Targ, R. (1976). A perceptual channel for information transfer over kilometer distances: historical perspective and recent research. *Proc. IEEE* 64:329–353.

Richards, M. A., Koren, S. A., Persinger, M. A. (2002). Circumcerebral application of weak complex magnetic fields with derivatives and changes in electroencephalographic power spectra within the theta range: implications for states of consciousness. *Percept. Motor Skills* 95:671–686.

Silberstein, R. B., Danielei, F., Nunez, P. L. (2003). Fronto-parietal evoked potential synchronization is increased during mental rotation. *Brain Imag*. 14:67–71.

Thomas, A. W., Kavaliers, M., et al. (1997). Pulsed magnetic field induced ''analgesia'' in the land snail, Capaea nemoralis, and the effects of mu, delta, kappa opioid receptors agonists/antagonists. *Peptides* 18:703–709.

Tononi, G., Edelman, G. N. (1998). Consciousness and complexity. *Science* 282:1846–1851.

Tsang, E. W., Koren, S. A., Persinger, M. A. (2004). Power increases within the gamma range over the frontal and occipital regions during acute exposures to cerebrally counterclockwise rotating magnetic fields with specific derivatives of change. *Int. J. Neurosci*. 114:183–1193.

Tu, L.-C., Luo, J., Gillies, G. T. (2005). The mass of the photon. *Reports Progr. Phys*. 68:77–130.

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